12

US Army Corps
of Engineers
Hydrologic Engineering Center

The Hydrologic Modeling System (HEC-HMS): Design and Development Issues

Technical Paper No. 149

June 1995

The Hydrologic Modeling System (HEC-HMS): Design and Development Issues

William Charley, Art Pabst and John Peters[1]

Abstract

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is a software package for precipitation-runoff simulation. Software development and architecture issues associated with development of HEC-HMS are described. The software's object-oriented structure and the role of its graphical user interface are presented.

Introduction

The Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers develops software for application in the disciplines of hydrologic and hydraulic engineering, and water resource planning. A project named NexGen is underway to develop "next-generation" software to replace current, widely-used software such as HEC-1 (for precipitation-runoff simulation) and HEC-2 (for steady-flow water surface profile computations).

The HEC-HMS, which will replace HEC-1, is intended for precipitation-runoff simulation using observed or hypothetical (design) precipitation. The user can select from a variety of technical options for each of the major computational elements: precipitation specification, loss estimation, excess-to-runoff transformation, and hydrologic routing. The program can be used to simulate runoff from complex subdivided watersheds, and can utilize distributed rainfall, which is now available from a new generation of weather radars. A basin "schematic" capability enables the user to configure the hydrologic elements of a watershed (such as subbasins, routing reaches, reservoirs, diversions) graphically, and to access editors and simulation results from schematic components. Requirements for the HEC-HMS include the following:

---

[1]Respectively, Hydraulic Engineer; Chief, Technical Assistance Division; and Senior Hydraulic Engineer; Hydrologic Engineering Center, 609 Second St., Davis, CA 95616-4687

Presented at the ASCE 2nd Congress on Computing in Civil Engineering, June 5-7, 1995, Atlanta, Georgia.

- state-of-the-art engineering algorithms
- comprehensive Graphical User Interface (GUI)
- substantial use of graphics
- operational in native X-window and Microsoft Windows environments
- substantial use and manipulation of time series data
- inter-program data exchange
- an interface to Geographic Information Systems
- use of existing computational algorithms written in FORTRAN
- extensible and easy to maintain
- distribution of the software unrestricted, with no run-time license fees

Languages, Toolkits and Libraries

Historically, HEC software was developed in FORTRAN, primarily by engineers. Development environments followed the typical progression of mainframe to mini-computer to personal computer and workstations. In preparation for NexGen software development, the "world" of windowing environments, event programming, GUI's, the C language, and finally, object oriented programming with C++ were explored. Prototype applications were developed. Initial skepticism with object-oriented programming turned into significant support for this technology; HEC-HMS is being developed with object oriented techniques.

To facilitate GUI development and porting to the requisite platforms, a commercial multi-platform toolkit was acquired. Although adoption of such a toolkit adds significantly to an already steep learning curve, the effort to develop and maintain separate platform-specific versions of source code is avoided. Some graphics are being developed with relatively low-level calls to routines in the multi-platform toolkit. A commercial graphics library was acquired to facilitate development of time series graphics. Versions of the graphics library are available for the various target platforms.

A specialized management system designed for efficient handling of time series data has been under progressive development since 1979. The Data Storage System (HEC-DSS) makes use of a library of routines that have capability to read and write variable-length, named records in a direct access file. Storage and retrieval of time series data is accomplished with blocks of data of pre-specified size based on the interval of the data. To facilitate use of HEC-DSS in object-oriented applications, a set of time series manager classes were developed that utilize the HEC-DSS library.

Existing HEC software contain a base of well documented and tested FORTRAN algorithms for performing hydrologic computations. The algorithms will be useful in the new software and have been incorporated into a library labeled *libHydro*. Thus, development of HEC-HMS draws on mixed languages (C++, C and FORTRAN), and utilizes a variety of libraries.

HEC-HMS Architecture

Figure 1 illustrates the internal architecture of HEC-HMS. Although linked into a single executable, there is a clear separation between the GUI and the simulation engine, where all computations are managed and performed. This permits independent development of the GUI and the engine, and facilitates the utilization of an alternative GUI in the future, should this become desirable. The GUI has access to objects within the engine through public interfaces. There are no references to the GUI from the engine, except for calls to a generic error message dialog box. The user interacts with the GUI through the windowing system, whether that is on an X device connected to a UNIX workstation, or Microsoft Windows on a PC.

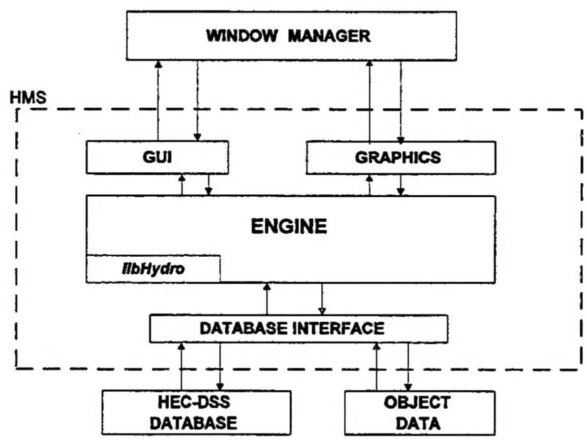

Figure 1 Software Architecture

For similar reasons, clear separations are maintained between the simulation engine and the graphics module, and the engine and the database interface module. The engine uses objects that interface to the database, and objects that perform graphics, but these objects could easily be modified to access a different database system or graphics package.

Currently, time series and similar data are stored using HEC-DSS, while persistent object data, such as parameters and coefficients, are stored in ASCII text files. The HEC-DSS provides a convenient and efficient way of entering, storing, retrieving and displaying series type data. ASCII text files provide a convenient means for testing the simulation engine independent of the GUI. It is anticipated that the text files may be replaced by a database in the future.

The engine is comprised of three major components: the project manager, the precipitation analysis model, and the basin runoff model. The project manager handles the control of the simulation time window, the utilization of precipitation and basin runoff models, file names, and various other management tasks. The precipitation analysis model computes subbasin average precipitation from either historical gaged data or from design

storms that are frequency-based or that utilize Standard Project Storm criteria. The basin runoff model uses this precipitation to compute subbasin discharge hydrographs, which can be routed through river reaches or reservoirs, and diverted or combined with other hydrographs.

Figure 2 illustrates use of objects in HEC-HMS. The BasinManager object creates, manages and destroys the various HydrologicElement objects that comprise the simulated watershed. When a compute is requested by the user, the BasinManager finds the hydrologic object which is acting as the outlet (all links, except for diversions, eventually point to this object), then sends it a message to compute. Because the outlet object requires hydrographs from objects above it for its computation, it requests objects upstream of itself to compute, which in turn request hydrographs from their upstream links. Thus, the request is propagated to all hydrologic objects that constitute the watershed.

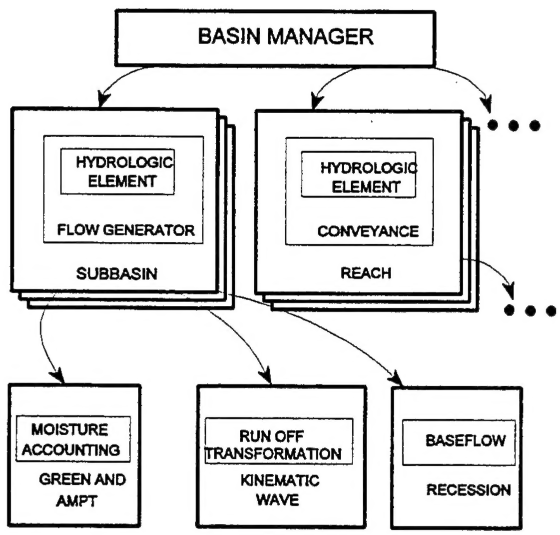

Figure 2 HEC-HMS Objects

Hydrologic classes inherit from a fundamental base class titled HydrologicElement. Data members of this class contain information pertinent to all element types, such as name, description, type, etc. The classes Conveyance, FlowGenerator, Node, and SinkBase each inherit from the HydrologicElement base class to provide certain types of connectivity functions. For example, the Conveyance class allows a link to one upstream object (from which to retrieve an inflow hydrograph), and one downstream object. The FlowGenerator class does not allow links to an upstream object; it can only link to downstream objects. Member functions of these classes provide a variety of capabilities, such as establishing and deleting links to other objects, and determining the cumulative basin area. The primary hydrologic classes, which inherit from these intermediate classes, are Reach and Reservoir (from Conveyance), Source and Subbasin (from FlowGenerator), Diversion and Junction (from Node), and Sink (from SinkBase). The data members of a derived class include data associated with its base class as well as data defined directly within the derived class.

Member functions of these classes provide the capability of setting and accessing data parameters, computing discharge hydrographs, and performing other desired object behaviors.

The primary hydrologic objects generally use "process" objects to implement the different computational methods. For example, Subbasin objects instantiate objects from a moisture accounting class, a runoff transform class, and a baseflow class. The object instantiated depends on the hydrologic method used. A GreenAmpt object or a InitialConstant object might be instantiated for moisture accounting, depending on the method selected by the user. A Snyder object, or Clark object, or Kinematic Wave object might be instantiated for the runoff transform. A process object has as data members the unique parameter data required for the particular method, and a member function to compute (e.g., compute excess given the precipitation). In many cases the "compute" member functions call routines from libHydro to perform the actual computation.

Each process class inherits from a base class for the process group that contains capabilities common to all the method classes within that group. For example, the moisture accounting base class defines time series objects to retrieve the subbasin precipitation and store the computed excess precipitation that are needed by all derived classes. Likewise the runoff transform base class defines time series objects that obtain the excess precipitation and store the computed hydrograph for all types of derived transform classes.

The TimeSeries class inherits from the DataManager class, which accesses the HEC-DSS database software. DataManager contains several "static" member functions, one of which points to buffers of data retrieved and stored. When an object retrieves (or stores) a set of data that is already in a memory buffer, no actual file access is required.

As previously indicated, persistent storage of data parameters and coefficients is presently achieved with ASCII text files. As an example of objects interacting and working with each other, when the user requests to save data parameters in persistent storage, the BasinManager sends a message to each hydrologic object to save its own data. After saving its data, each hydrologic object in turn sends a message to its processor objects to save their data. To re-establish a "model" from a persistent data file, a data loading object recreates hydrologic objects via the BasinManager, and sets their data parameters and coefficients through their public interfaces. In this procedure, as far as the engine is concerned, the objects are created and parameters set just as if this action were being done by the user through the GUI.

Graphical User Interface

The GUI is the window through which the user interacts with HEC-HMS. It enables specification of information to be retrieved or stored (e.g., data files), specification of application-specific information (both data and task instructions), and viewing of results. The GUI enables the user to easily and effectively perform the various types of analysis for which the program is capable.

With the GUI, the user can define, change, control, and view a model's configuration, inputs and results. The multiple windows shown in Figure 3 illustrates some of the screens that comprise the GUI for an example watershed. The screens are, in a

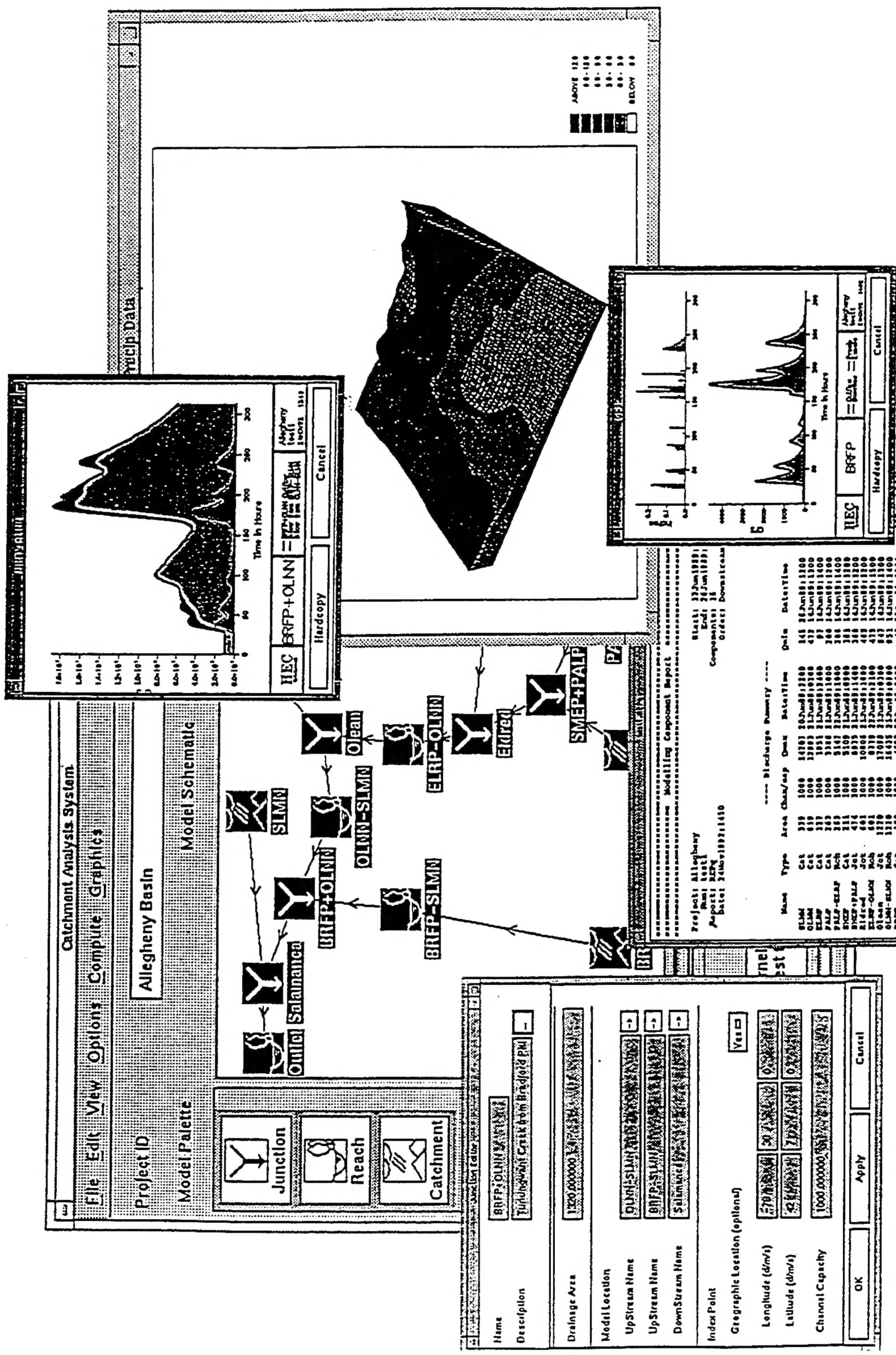

Figure 3 Graphical User Interface

counter clockwise order from the upper left: 1) the schematic configuration of hydrologic elements that make up the example Allegheny Basin model; 2) a data editor for entering or changing information for a junction object; 3) a tabular report of critical flows for each hydrologic element; 4) a graphic of subbasin precipitation and flow results; 5) a perspective view of a precipitation field over the entire basin; and 6) a graphic of the flows entering and leaving a junction. Each of these windows make up a portion of the complete GUI. The user may open any number of graphical and tabular windows to display reports and model information for any hydrologic element of interest.

The user-controlled schematic representation of the components of a hydrologic system is a key element of the GUI. The schematic employs icons to represent subbasins, routing reaches, reservoirs, diversions, etc., and their topological connections. In creating a new watershed model, the user selects an element type (e.g., subbasin) from a popup menu and drags it to a desired location on the schematic background. Other elements are established in a similar fashion, as are connecting links between elements. An element can then be selected, and access to a data editor for that element is provided as an option from a popup menu. After a simulation has been executed, an element can again be selected, and a popup menu provides access to a display of simulation results for that element.

Navigation through the schematic is facilitated with a view finder window that shows a miniature view of the entire schematic, and a frame around that portion of the schematic presently visible. The user can move the frame to bring other portions of the schematic into view. Capability is also provided to "collapse" portions of the schematic so that unwanted detail can be hidden from view.

The schematic capability is required in a number of NexGen software products besides HEC-HMS, such as those for simulating reservoir systems and river hydraulics, and for analyzing flood damage. Hence the approach for developing the capability was to develop a Schematic Model Library (SML) which consists of C++ classes for general application. The SML links with libraries from the multi-platform toolkit so that the schematic capability is portable across platforms.

Where several GUI windows display the same data value or information related to a data value, it is necessary to provide a mechanism to assure that the contents of all windows remain current. If, for example, the drainage area in the data edit window were changed, then the tabular report, which shows each element's area, would need to be updated. All model results that are affected by the drainage area value would no longer be current. To provide a mechanism to systematically handle the update of windows, "observer" objects are used. An observer object allows a window to register its interest in being notified when specific model data is changed. Thus, the object that generates the report could use an observer object to notify a hydrologic element object of its interest in knowing of a change in drainage area. The report object would then be able to update the particular data value, or regenerate the complete report.

While the user is able to interact with the model through the GUI to accomplish her or his modeling needs, it is frequently desirable to repeat a sequence of model interactions over and over again with different model parameters. Under this scenario the GUI as the means of carrying out repeated operations can become the user's greatest frustration. A similar need for an alternate to the GUI model control capability occurs when a model must

be operated unattended, or under the control of another higher level modeling process that sees the hydrologic model as only a contributing component. In each of these cases the ability to drive the model from a script of instructions which include both control and data values is needed. In its full implementation the model design will permit the user to define any number of macro scripts that can be invoked to simplify often repeated model GUI sequences. An example might be a tool bar allowing the selection of a macro to trigger the routine generation of six hardcopy plots and four reports to summarize model results.

The GUI design requires careful consideration of many issues such as, the mental image a user will have of the problem solving steps, logical navigation through those steps, the organization of related data into specific GUI screens, the aesthetic layout of the information on each screen, look and feel consistent with the parent windowing system, and adequate handling of error conditions.

Closing Comment

The current architecture and development plans for HEC-HMS reflect the set of requirements listed in the Introduction and experience to date in model development. While the learning curves have been steep and initial development has progressed much more slowly than was originally anticipated, we find that we are now able to extend existing modeling capabilities and continue model development in a reasonably efficient and straight forward manner. We also anticipate that software maintenance will be facilitated, and that future adoption of alternative graphics, GUI or database features will not require a major rewrite of the computational engine or other components.

Acknowledgements

Anthony Slocum has contributed significantly to the design of HEC-HMS and is the developer of the Schematic Model Library. Paul Ely is the developer of libHydro.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1995

3. REPORT TYPE AND DATES COVERED
Technical Paper

4. TITLE AND SUBTITLE
The Hydrologic Modeling System (HEC-HMS):
Design and Development Issues

5. FUNDING NUMBERS

6. AUTHOR(S)
William Charley, Art Pabst and John Peters

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Hydrologic Engineering Center
609 Second Street
Davis, California 95616

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Paper No. 149

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Water Resources Support Center
7701 Telegraph Road
Alexandria VA 22310-3868

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Presented at the ASCE 2nd Congress on Computing in Civil Engineering, June 5-7, 1995, Atlanta, Georgia.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is a software package for precipitation-runoff simulation. Software development and architecture issues associated with development of HEC-HMS are described. The software's object-oriented structure and the role of its graphical user interface are presented.

14. SUBJECT TERMS
Precipitation-runoff simulation, software architecture

15. NUMBER OF PAGES
8

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED			

TECHNICAL PAPER SERIES

TP-1 Use of Interrelated Records to Simulate Streamflow
TP-2 Optimization Techniques for Hydrologic Engineering
TP-3 Methods of Determination of Safe Yield and Compensation Water from Storage Reservoirs
TP-4 Functional Evaluation of a Water Resources System
TP-5 Streamflow Synthesis for Ungaged Rivers
TP-6 Simulation of Daily Streamflow
TP-7 Pilot Study for Storage Requirements for Low Flow Augmentation
TP-8 Worth of Streamflow Data for Project Design - A Pilot Study
TP-9 Economic Evaluation of Reservoir System Accomplishments
TP-10 Hydrologic Simulation in Water-Yield Analysis
TP-11 Survey of Programs for Water Surface Profiles
TP-12 Hypothetical Flood Computation for a Stream System
TP-13 Maximum Utilization of Scarce Data in Hydrologic Design
TP-14 Techniques for Evaluating Long-Term Reservoir Yields
TP-15 Hydrostatistics - Principles of Application
TP-16 A Hydrologic Water Resource System Modeling Techniques
TP-17 Hydrologic Engineering Techniques for Regional Water Resources Planning
TP-18 Estimating Monthly Streamflows Within a Region
TP-19 Suspended Sediment Discharge in Streams
TP-20 Computer Determination of Flow Through Bridges
TP-21 An Approach to Reservoir Temperature Analysis
TP-22 A Finite Difference Method for Analyzing Liquid Flow in Variably Saturated Porous Media
TP-23 Uses of Simulation in River Basin Planning
TP-24 Hydroelectric Power Analysis in Reservoir Systems
TP-25 Status of Water Resource Systems Analysis
TP-26 System Relationships for Panama Canal Water Supply
TP-27 System Analysis of the Panama Canal Water Supply
TP-28 Digital Simulation of an Existing Water Resources System
TP-29 Computer Applications in Continuing Education
TP-30 Drought Severity and Water Supply Dependability
TP-31 Development of System Operation Rules for an Existing System by Simulation
TP-32 Alternative Approaches to Water Resource System Simulation
TP-33 System Simulation for Integrated Use of Hydroelectric and Thermal Power Generation
TP-34 Optimizing Flood Control Allocation for a Multipurpose Reservoir
TP-35 Computer Models for Rainfall-Runoff and River Hydraulic Analysis
TP-36 Evaluation of Drought Effects at Lake Atitlan
TP-37 Downstream Effects of the Levee Overtopping at Wilkes-Barre, PA, During Tropical Storm Agnes
TP-38 Water Quality Evaluation of Aquatic Systems
TP-39 A Method for Analyzing Effects of Dam Failures in Design Studies
TP-40 Storm Drainage and Urban Region Flood Control Planning
TP-41 HEC-5C, A Simulation Model for System Formulation and Evaluation
TP-42 Optimal Sizing of Urban Flood Control Systems
TP-43 Hydrologic and Economic Simulation of Flood Control Aspects of Water Resources Systems
TP-44 Sizing Flood Control Reservoir Systems by Systems Analysis
TP-45 Techniques for Real-Time Operation of Flood Control Reservoirs in the Merrimack River Basin
TP-46 Spatial Data Analysis of Nonstructural Measures
TP-47 Comprehensive Flood Plain Studies Using Spatial Data Management Techniques
TP-48 Direct Runoff Hydrograph Parameters Versus Urbanization
TP-49 Experience of HEC in Disseminating Information on Hydrological Models
TP-50 Effects of Dam Removal: An Approach to Sedimentation
TP-51 Design of Flood Control Improvements by Systems Analysis: A Case Study
TP-52 Potential Use of Digital Computer Ground Water Models
TP-53 Development of Generalized Free Surface Flow Models Using Finite Element Techniques
TP-54 Adjustment of Peak Discharge Rates for Urbanization
TP-55 The Development and Servicing of Spatial Data Management Techniques in the Corps of Engineers
TP-56 Experiences of the Hydrologic Engineering Center in Maintaining Widely Used Hydrologic and Water Resource Computer Models
TP-57 Flood Damage Assessments Using Spatial Data Management Techniques
TP-58 A Model for Evaluating Runoff-Quality in Metropolitan Master Planning
TP-59 Testing of Several Runoff Models on an Urban Watershed
TP-60 Operational Simulation of a Reservoir System with Pumped Storage
TP-61 Technical Factors in Small Hydropower Planning
TP-62 Flood Hydrograph and Peak Flow Frequency Analysis
TP-63 HEC Contribution to Reservoir System Operation
TP-64 Determining Peak-Discharge Frequencies in an Urbanizing Watershed: A Case Study
TP-65 Feasibility Analysis in Small Hydropower Planning
TP-66 Reservoir Storage Determination by Computer Simulation of Flood Control and Conservation Systems
TP-67 Hydrologic Land Use Classification Using LANDSAT
TP-68 Interactive Nonstructural Flood-Control Planning
TP-69 Critical Water Surface by Minimum Specific Energy Using the Parabolic Method
TP-70 Corps of Engineers Experience with Automatic Calibration of a Precipitation-Runoff Model
TP-71 Determination of Land Use from Satellite Imagery for Input to Hydrologic Models
TP-72 Application of the Finite Element Method to Vertically Stratified Hydrodynamic Flow and Water Quality

TP-73 Flood Mitigation Planning Using HEC-SAM
TP-74 Hydrographs by Single Linear Reservoir Model
TP-75 HEC Activities in Reservoir Analysis
TP-76 Institutional Support of Water Resource Models
TP-77 Investigation of Soil Conservation Service Urban Hydrology Techniques
TP-78 Potential for Increasing the Output of Existing Hydroelectric Plants
TP-79 Potential Energy and Capacity Gains from Flood Control Storage Reallocation at Existing U. S. Hydropower Reservoirs
TP-80 Use of Non-Sequential Techniques in the Analysis of Power Potential at Storage Projects
TP-81 Data Management Systems for Water Resources Planning
TP-82 The New HEC-1 Flood Hydrograph Package
TP-83 River and Reservoir Systems Water Quality Modeling Capability
TP-84 Generalized Real-Time Flood Control System Model
TP-85 Operation Policy Analysis: Sam Rayburn Reservoir
TP-86 Training the Practitioner: The Hydrologic Engineering Center Program
TP-87 Documentation Needs for Water Resources Models
TP-88 Reservoir System Regulation for Water Quality Control
TP-89 A Software System to Aid in Making Real-Time Water Control Decisions
TP-90 Calibration, Verification and Application of a Two-Dimensional Flow Model
TP-91 HEC Software Development and Support
TP-92 Hydrologic Engineering Center Planning Models
TP-93 Flood Routing Through a Flat, Complex Flood Plain Using a One-Dimensional Unsteady Flow Computer Program
TP-94 Dredged-Material Disposal Management Model
TP-95 Infiltration and Soil Moisture Redistribution in HEC-1
TP-96 The Hydrologic Engineering Center Experience in Nonstructural Planning
TP-97 Prediction of the Effects of a Flood Control Project on a Meandering Stream
TP-98 Evolution in Computer Programs Causes Evolution in Training Needs: The Hydrologic Engineering Center Experience
TP-99 Reservoir System Analysis for Water Quality
TP-100 Probable Maximum Flood Estimation - Eastern United States
TP-101 Use of Computer Program HEC-5 for Water Supply Analysis
TP-102 Role of Calibration in the Application of HEC-6
TP-103 Engineering and Economic Considerations in Formulating
TP-104 Modeling Water Resources Systems for Water Quality
TP-105 Use of a Two-Dimensional Flow Model to Quantify Aquatic Habitat
TP-106 Flood-Runoff Forecasting with HEC-1F
TP-107 Dredged-Material Disposal System Capacity Expansion
TP-108 Role of Small Computers in Two-Dimensional Flow Modeling
TP-109 One-Dimensional Model For Mud Flows
TP-110 Subdivision Froude Number
TP-111 HEC-5Q: System Water Quality Modeling
TP-112 New Developments in HEC Programs for Flood Control
TP-113 Modeling and Managing Water Resource Systems for Water Quality
TP-114 Accuracy of Computed Water Surface Profiles - Executive Summary
TP-115 Application of Spatial-Data Management Techniques in Corps Planning
TP-116 The HEC's Activities in Watershed Modeling
TP-117 HEC-1 and HEC-2 Applications on the MicroComputer
TP-118 Real-Time Snow Simulation Model for the Monongahela River Basin
TP-119 Multi-Purpose, Multi-Reservoir Simulation on a PC
TP-120 Technology Transfer of Corps' Hydrologic Models
TP-121 Development, Calibration and Application of Runoff Forecasting Models for the Allegheny River Basin
TP-122 The Estimation of Rainfall for Flood Forecasting Using Radar and Rain Gage Data
TP-123 Developing and Managing a Comprehensive Reservoir Analysis Model
TP-124 Review of the U.S. Army Corps of Engineering Involvement With Alluvial Fan Flooding Problems
TP-125 An Integrated Software Package for Flood Damage Analysis
TP-126 The Value and Depreciation of Existing Facilities: The Case of Reservoirs
TP-127 Floodplain-Management Plan Enumeration
TP-128 Two-Dimensional Floodplain Modeling
TP-129 Status and New Capabilities of Computer Program HEC-6: "Scour and Deposition in Rivers and Reservoirs"
TP-130 Estimating Sediment Delivery and Yield on Alluvial Fans
TP-131 Hydrologic Aspects of Flood Warning - Preparedness Programs
TP-132 Twenty-five Years of Developing, Distributing, and Supporting Hydrologic Engineering Computer Programs
TP-133 Predicting Deposition Patterns in Small Basins
TP-134 Annual Extreme Lake Elevations by Total Probability Theorem
TP-135 A Muskingum-Cunge Channel Flow Routing Method for Drainage Networks
TP-136 Prescriptive Reservoir System Analysis Model - Missouri River System Application
TP-137 A Generalized Simulation Model for Reservoir System Analysis
TP-138 The HEC NexGen Software Development Project
TP-139 Issues for Applications Developers
TP-140 HEC-2 Water Surface Profiles Program
TP-141 HEC Models for Urban Hydrologic Analysis
TP-142 Systems Analysis Applications at the Hydrologic Engineering Center
TP-143 Runoff Prediction Uncertainty for Ungauged Agricultural Watersheds
TP-144 Review of GIS Applications in Hydrologic Modeling
TP-145 Application of Rainfall-Runoff Simulation for Flood Forecasting
TP-146 Application of the HEC Prescriptive Reservoir Model in the Columbia River System
TP-147 HEC River Analysis System (HEC-RAS)
TP-148 HEC-6: Reservoir Sediment Control Applications
TP-149 The Hydrologic Modeling System (HEC-HMS): Design and Development Issues